Management Model for Predicting Fall Lamb:Ewe Ratios in Desert Bighorn Sheep, Canyonlands National Park, Utah

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Abstract. The status of the bighorn sheep (*Ovis canadensis*) herd in Canyonlands National Park is of concern to managers. The Island-in-the-Sky herd is harvested for transplanting, and herd recovery following removals in 1982–85 has been below expectations. Weather and survey data for 1976–85 were used to develop a predictive model for lamb:ewe ratios that would be expected on fall surveys; data for 1986–89 were used to test the model. Three predictive variables—maximum temperatures in May and precipitation in April the year of the survey and precipitation from January through March 2 years before bighorn surveys—had strong, significant relations to lamb counts. These variables were correlated with each other; therefore, the data were analyzed by principal components analysis. The best predictive model was developed by regressing the first principal component with lamb:ewe ratios for the 10-year period. The model was significant ($P = 0.001$) and explained 76% of the variation in lamb:ewe ratios for 1976–85 (SE = 9). The selected variables were important in vegetative growth—biomass and forage quality apparently control bighorn population dynamics in Canyonlands National Park.

Actual lamb:ewe ratios averaged eight lambs less than the predicted ratios for 1986–89. Maximum temperature in May was in the upper quartile of its range in 1988 and 1989 and may have negatively influenced lamb survival. Removals of animals for transplants in 1982–85 were biased toward ewes and may have affected age structure of ewes, resulting in fewer lambs being produced than would be expected.

Key words: Bighorn sheep, Canyonlands National Park, ewe, lamb, *Ovis canadensis*, ratios.

The Island-in-the-Sky (ISKY) herd of desert bighorn (*Ovis canadensis*) in Canyonlands National Park, consisting of 200–300 animals, is the largest and most productive herd in southern Utah. Since 1975, the herd has been the primary source of animals for transplantation by the Utah Division of Wild-

life Resources. Between 1982 and 1985, 87 animals (20 males, 54 females, 13 lambs) were removed. Alarmed by low lamb:ewe ratios and slow herd recovery in the years following removals, the National Park Service suspended transplanting operations in 1985. I attempted to evaluate and isolate factors influencing the slow herd recovery by examining the relations of weather and lamb:ewe ratios before and after transplant removals.

Weather has direct and indirect effects on individual animals in wildlife populations (Picton 1979). Weather, cover, and nutrition interact either positively or negatively to influence individuals. At northern latitudes or high elevations, deep snow may, on occasion, restrict movements of animals and compromise their abilities to thermoregulate and to seek food (Picton 1979). Windchill and low minimum temperatures may influence survival of the animals. In arid areas, drought may decrease or eliminate water resources and may have serious indirect effects on wildlife by affecting the growth and nutrient content of forage plants. Understanding effects of weather on wildlife is of primary importance to management of their populations, but these interactions have only recently been studied for wildlife on arid lands. By understanding factors regulating wildlife populations in a given locale, wildlife managers can better interpret years having low or high survival of young animals. Understanding regulating factors is critical if management action is to be focused on factors whose manipulation will elicit a population response (Leopold 1933).

Because positive and detrimental effects of weather on wildlife populations are so generally apparent, numerous studies have been conducted on the relations of mortality and population growth to weather. For example, the growth rate of kangaroo populations is positively related to rainfall and pasture biomass (Caughley et al. 1987). Kangaroo populations are decimated periodically by drought (Caughley et al. 1985). Rainfall can control winter sparrow densities (Laurance and Yensen 1985) and greater kudu populations (Owen-Smith 1990). Climatic indices have been developed as a management tool for predicting reproduction and fawn survival in wapiti (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and northern bighorn sheep (Verme 1968; Picton 1979, 1984; Bartmann and Bowen 1984). Only recently have models been developed to help explain the relations of climate and lamb survival in desert bighorn sheep (Wehausen 1980; Holl and Bleich 1983; Douglas and Annable 1985; Douglas and Leslie 1986; Douglas 1991). Population dynamics of desert bighorns have been related to precipitation and herd density (Douglas and Leslie 1986; Wehausen et al. 1987). Herd density was secondary to precipitation in its influence. The effects of weather are complex and multidimensional. Weather can affect forage nutrition, body condition, ovulation, and postpartum survival of lambs. Drought can affect availability of nutritious forage and influence gestation and health of the fetus.

My hypotheses were that weather parameters that regulate production of nutritious and abundant forage secondarily regulate lamb survival in the

ISKY herd and that aberrant weather or transplant removals may have depressed herd recovery. I present a model for predicting bighorn lamb:ewe ratios from weather data for the ISKY herd, Canyonlands National Park, Utah.

Weather variables are used in the model as a surrogate for forage production. Lamb:ewe ratios are used as an index of lamb production or postpartum survival. Data on predation and herd density are not available for testing, but these parameters were thought not to be the primary controlling factors of the ISKY herd at this time. The ISKY is a large area that has abundant escape terrain and forage relative to the number of bighorn occupying it. There is no physical evidence to suggest that efforts of mammalian predators limit the numbers of bighorns in the ISKY.

Methods

Because timing of precipitation and other weather events is as important to plant growth as amounts per se; the monthly relations of precipitation, moisture demand by foliage, and soil moisture storage were calculated and graphed (Table 1; Fig. 1). The graphs depict the yearly soil moisture cycle for ISKY and help identify months in which precipitation recharges the soil and helps initiate the growing season (Mather 1979).

Weather records for 1976 through 1989 were obtained from the park and from National Oceanographic and Atmospheric Administration summaries for the Neck Weather Station, the closest weather station to the ISKY bighorn herd. The first 10 years of data were used for model development; the remaining 4 years were used to test the predictive validity of the model (Table 2).

Bighorn surveys have been conducted in the ISKY each fall from 1976 to 1989 by Utah Department of Wildlife Resources in conjunction with park personnel. Yearly lamb:ewe ratios were calculated from the survey data.

Weather variables and yearly lamb:ewe ratios were used to prepare summary statistics and correlation, partial correlation, and covariance matrices. The matrices were used to select the weather variables most highly correlated with lamb:ewe ratios. All available weather data were tested by month and combinations of months against lamb:ewe ratios; no a priori assumptions were made about which weather variables and which months would correlate with lamb:ewe ratios. The dependent variable for regression analyses was numbers of lambs and ewes seen on fall surveys, expressed as lambs/100 ewes. Independent variables included monthly means of daily maximum and minimum air temperatures, monthly means of daily soil temperatures at Ridgefield (the nearest station), total monthly precipitation, and wind. Values of each variable (means or totals) for individual months and combinations of 2, 3, 4, 6, and 12 successive monthly values within a given year were regressed against yearly lamb:ewe ratios by simple linear regression. Lag effects of weather on lambs were evaluated by using weather data

Table 1. Monthly average moisture measurements[a] in Canyonlands National Park, Utah, 1976–1989, following Mather (1979).

Variable	J	F	M	A	M	J	J	A	S	O	N	D	Total
PE[b]	0	0	1.57	5.03	8.43	13.23	16.21	13.39	8.71	4.39	1.27	0	72.23
PPT[c]	1.29	0.97	2.69	2.26	2.08	0.99	2.82	1.83	2.34	2.67	2.44	1.53	23.73
PPT – PE[d]	1.29	0.97	1.12	−2.77	−6.35	−12.24	−13.39	−11.56	−6.38	−1.73	1.17	1.53	
Storage[e]	10.16	10.16	10.16	7.39	3.81	−2.08	−3.26	−1.40	3.78	5.86	10.16	10.16	
Surplus[f]	1.29	0.79	1.12	0	0	0	0	0	0	0	1.17	1.35	5.72

[a] All measurements are in centimeters.
[b] Potential evapotranspiration.
[c] Precipitation.
[d] Precipitation minus potential evapotranspiration.
[e] Soil moisture storage.
[f] Soil moisture surplus.

for individual months and combinations of months from 1 and 2 years before lambing. Only those variables used in constructing the final models are presented (Table 2).

Weather variables having the strongest correlation with lamb:ewe ratios were used in multiple regressions to develop a predictive model. The simplest model explaining the greatest amount of variation in lamb:ewe ratios—and having the best predictability—was selected. Residuals from regressions were summarized, plotted and examined for patterns, and plotted against probability plots. The resulting models were tested by ANOVA. The 95% prediction interval was developed for each regression model.

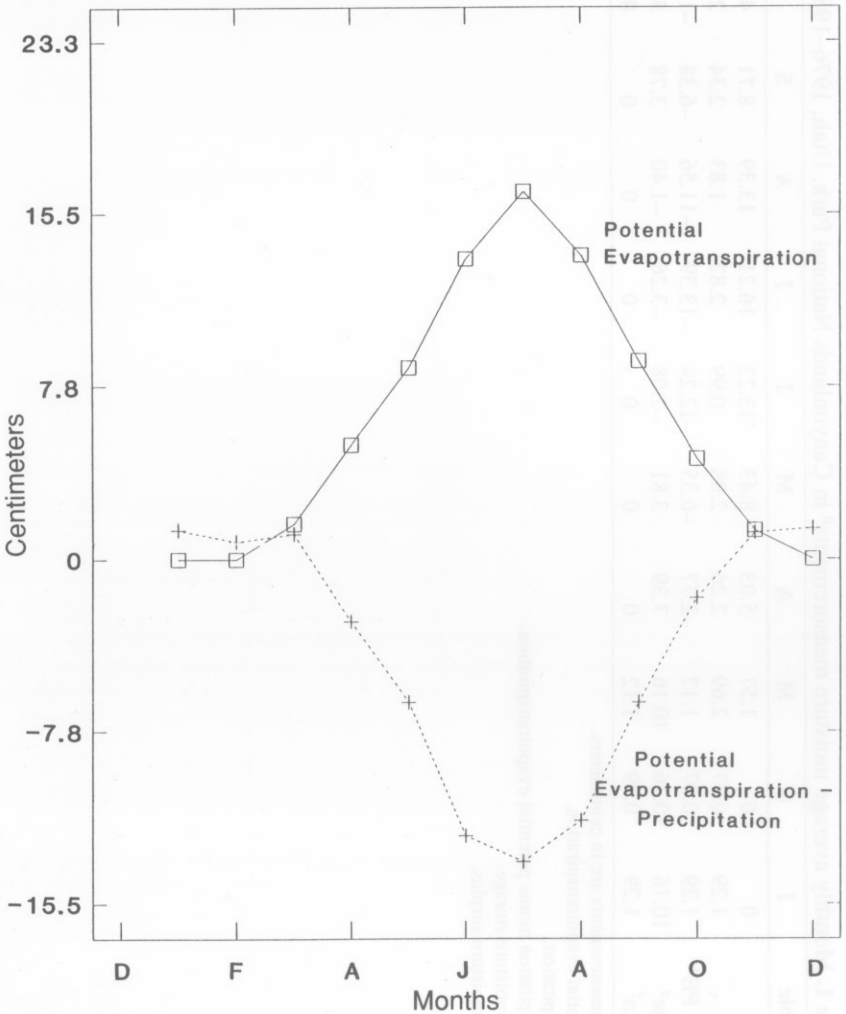

Fig. 1. Calculated monthly potential evapotranspiration (*squares*) and precipitation minus evapotranspiration (soil moisture storage; +) for Island-In-The-Sky, Canyonlands National Park, Utah.

Table 2. Numbers of bighorn (*Ovis canadensis*) lambs:100 ewes, predicted lamb:ewe ratios, and weather variables entering management model for prediction of lamb numbers in the Island-In-The-Sky herd, Canyonlands National Park, Utah.

Year	Lambs: 100 ewes	Predicted lambs		Maximum temperature	Precipitation (cm)	
		Model 2	Model 1	May (°C)	April	2-year lag Jan.–Mar.
1976	38	48	48	24.39	0.61	5.33
1977	56	52	52	22.83	1.75	5.97
1978	39	36	36	23.22	5.36	3.81
1979	59	49	46	21.56	0.91	1.24
1980	67	70	70	19.39	2.26	9.02
1981	57	61	61	21.17	1.80	7.26
1982	77	72	72	21.33	0.15	10.46
1983	52	63	62	19.44	1.47	5.11
1984	15	23	23	24.67	6.63	2.24
1985	59	46	47	22.83	4.83	7.16
1986	33	28	42	21.44	4.22	2.57
1987	35	46	59	22.00	0.15	6.22
1988	32	49	43	24.17	1.32	4.09
1989	29	37	54	23.78	0.18	6.73

The variables that were selected because of their high correlation with lamb:ewe ratios were also intercorrelated. The first models were developed with nontransformed data sets, then log-transformed data were used in an attempt to decrease multicollinearity and to improve predictability. Data were also analyzed by principal components analysis (PCA). The resulting principal components were regressed against lamb:ewe ratios for model development.

Study Area

The ISKY is a large, highly dissected, peninsular mesa in the northern part of Canyonlands National Park. The ISKY land mass towers 607 m above the surrounding canyon bottoms. Elevations range from about 1,219 m at river level to 1,829 m on top of the mesa. The ISKY is nearly segregated from other parts of the park by the Green and Colorado rivers, which have their confluence at its southern tip.

Climate in the region is semiarid, and yearly precipitation averaged 23.8 cm for 1974–90. Late winter–early spring precipitation (about January–May) initiates and extends the growing season.

Loope (1977) identified seven vegetation types in the park: talus slopes with sparse grasses and shrubs, blackbrush flats, saltbrush flats, grassland flats, Cutler slopes with varying shrubs, pinyon–juniper areas on flats and slopes, and tamarisk and willow thickets along rivers.

Results and Discussion

Wildlife should be relatively well adapted to the climate of the region in which they live, and births should occur when nutritious forage is most predictably available. In ISKY, lambing in bighorn sheep occurs from about late March to early May. Other studies of population dynamics of desert bighorns have shown that weather variables regulating vegetative growth also influence lamb survival (Wehausen 1980; Holl and Bleich 1983; Douglas and Leslie 1986; Wehausen et al. 1987). Vegetative growth and its nutrient content can affect lamb survival pre- or postpartum. Nutritional forage is especially important to bighorn ewes during the last trimester of gestation (when the fetus is growing rapidly) and during lactation when nutritional needs are highest. Lambs require high nutrient intake when they begin foraging to the exclusion of nursing. Precipitation records for ISKY were used in conjunction with the calculated heat index and correction factors (Mather 1979) to estimate potential evapotranspiration and soil moisture storage for average years. Potential evapotranspiration, or moisture demand by vegetation, escalates rapidly from about March to a seasonal extreme in July (Fig. 1). Soil moisture begins to decrease in April and reaches negative

storage in June (Table 1). The intersecting curves of soil moisture and evapotranspiration suggest that, in average years, drying of forage species begins in May (Fig. 1). Hull (1984) found that protein content of bighorn forage species began to decrease in May 1983, then continued to decrease rapidly in successive months. The weather data and calculations of moisture demand by the vegetation (Table 1; Fig. 1) suggest that the pattern represents the norm.

Lamb:ewe ratios and weather parameters used in model development are shown in Table 2. Correlations (Table 3) of monthly means of temperatures and precipitation, with yearly lamb:ewe ratios for 1976–85 yielded three weather variables significantly related to lamb:ewe ratios. The three were April precipitation ($r = -0.653$, $P = 0.04$) and maximum temperatures in May ($r = -0.703$, $P = 0.02$) the year the lambs were born and precipitation from January through March 2 years before the lambs were born ($r = 0.700$, $P = 0.02$). The 2-year lag is thought to reflect body condition in ewes before conception (Wehausen 1980). It also is possible that this lag may reflect bud initiation in perennial shrubs; buds are formed in the year preceding that in which they open.

An earlier modeling attempt for the ISKY herd also identified spring precipitation and spring maximum temperatures as being the important predictors of lamb:ewe ratios (Douglas and Annable 1985). In the 1985 model, spring was identified as March through May. The present model supports the importance of these two parameters, and the enlarged data base allows better identification of specific months in spring when precipitation and maximum temperatures exert their negative influences on lambs.

The three selected variables were used in a multiple regression with lamb:ewe ratios to develop a predictive equation. When considered individually, none of the three variables entering the model was significant at

Table 3. Correlation analysis of bighorn (*Ovis canadensis*) lambs:100 ewes, principal components 1 (PC1) and 2 (PC2); mean maximum temperature in May (MTMAY); April precipitation (PAPR); and precipitation January through March 2 years before lambs were born (P2JM) in Canyonlands National Park, Utah.

	Lambs	PC1	PC2	MTMAY	PAPR	P2JM
Lambs	1.0000	−0.8714	0.0631	−0.7206	−0.6533	0.7001
	0.0000[a]	0.0010	0.8626	0.0235	0.0405	0.0242
PC1	−0.8714	1.0000	0.0000	0.8188	0.7817	−0.7568
	0.0010[a]	0.0000	1.0000	0.0038	0.0076	0.113
PC2	0.0631	0.0000	1.0000	0.1070	0.4877	0.6195
	0.8626[a]	1.0000	0.0000	0.7687	0.1528	0.0561
MTMAY	−0.7026	0.8188	0.1070	1.0000	0.4730	−0.4357
	0.0235[a]	0.0038	0.7687	0.0000	0.1674	0.2081

[a] Probability.

$P < 0.05$, yet the resulting model was highly significant (Table 4). This results from all three variables being intercorrelated (Table 3) and indicates that they must be considered together to have predictive value. The resultant regression explained 76% of the variability in lamb:ewe ratios for 1976–85, (R^2 adjusted for d.f. = 0.645, $P = 0.026$). The resulting model (1) for predicting the lamb:ewe ratio is

Lamb:ewe ratio = 182.03 + 6.47 (precipitation in January through March, 2 years before) − 1.93 (maximum temperature in May) − 6.46 (precipitation in April). (1)

Standard error of the estimate is 10.36. The 95% prediction interval is ±14 lambs (McClave and Dietrich 1988). Maximum temperatures in May and precipitation in April refer to the same year in which lambs were counted.

The global usefulness of the model was tested by ANOVA following McClave and Dietrich (1988:780). The calculated $F = 6.45$ (d.f. = 3, 6) for the model had a $P = 0.026$, indicating that the model is useful. The model must have shown its usefulness at this point or it would not have been given further consideration.

The model did not predict lamb:ewe ratios well; predictions for 1987 and 1989 were 14 and 25 lambs higher than observed. Because of the intercorrelation of variables (Table 3), additional analyses were conducted in

Table 4. Model fitting and ANOVA for Model 1, using untransformed data from Canyonlands National Park, Utah (**A**), and analysis of variance for the full regression (**B**).

A

Individual variable	Coefficient[a]	SE[b]	T-value[c]	Significance level[d]
Constant	182.0264	91.1850	1.9962	0.0929
Maximum temperature/May	−1.9266	1.2518	−1.5392	0.1747
Precipitation/April	−6.4583	4.5864	−1.4081	0.2087
Precipitation/January–March	6.4669	3.4692	1.8641	0.1116

B[e]

Source	Sum of squares	D.F.	Mean square	F-ratio	P-value
Model	2,078.63	3	692.878	6.4527	0.0263
Error	644.27	6	107.378		
Total (corrected)	2,722.90	9			

[a] R^2 (adjusted) = 0.6451.
[b] SE = 10.3623.
[c] MAE = 7.1798.
[d] Durban–Watson = 1.922.
[e] $R^2 = 0.7634$; SE of estimate = 10.3623; R^2 (adjusted for d.f.) = 0.6451; Durban–Watson = 1.9219.

an effort to develop a model free of multicollinearity. A new model based on log-transformed data yielded only slightly better predictability.

Principal components analysis was then used to analyze the three independent variables and to eliminate intercorrelations between them. Principal components analysis finds combinations of the original variables and produces indices (the principal components) that are not correlated and that measure different dimensions of the data. The best results are obtained when the original variables are highly correlated (Manly 1986). The first principal component explains the greatest amount of variation in the data, the second component the second largest amount, and so on.

Principal component one explained 62% of the variation, and principal component two explained 21%. Principal component one was positively correlated ($r = 0.82$) with maximum temperatures in May and precipitation in April ($r = 0.78$) and negatively correlated with lamb:ewe ratios ($r = -0.87$) and precipitation from January to March 2 years before lambing ($r = -0.76$). Principal component two was positively correlated with precipitation from January to March 2 years before lambing ($r = 0.62$) and to a lesser extent with precipitation in April ($r = 0.49$).

The first two principal components were regressed against lamb:ewe ratios by multiple regression. Principal component two entered the model at $P = 0.74$, but the resulting model was highly significant ($P = 0.006$) and yielded better predictions than earlier models. Because principal component one includes information from all of the independent variables, a new model was developed using only principal component one regressed against lamb:ewe ratios (Table 5). This model (2) was highly significant ($R^2 = 0.76$, R^2 ad-

Table 5. Model fitting and ANOVA for the first principal component regressed against bighorn (*Ovis canadensis*) lambs:100 ewes for Canyonlands National Park, Utah (**A**), and analysis of variation for the full regression (**B**).

A

Individual variable	Coefficient[a]	SE[b]	T-value[c]	Significance level[d]
Constant	51.8999	2.8619	118.1346	0.0000
Principal component 1	−11.13029	2.2154	−5.0243	0.0010

B[e]

Source	Sum of squares	D.F.	Mean square	F-ratio	P-value
Model	2,067.650	1	2,067.650	25.244	0.0010
Error	655.251	8	81.906		
Total (corrected)	2,722.90	9			

[a] R^2 (adjusted) = 0.7293.
[b] SE = 9.0502.
[c] MAE = 7.2242.
[d] Durban–Watson = 1.889.
[e] $R^2 = 0.759356$; SE of estimate = 9.05021; R^2 (adjusted for d.f.) = 0.729275.

justed for d.f. = 0.73, $P = 0.0010$) and explains 76% of the variance in lamb:ewe ratios for the 10 years of data. Model 2, although more difficult for managers to use, is superior to the other models and is a better predictor of lamb:ewe ratios (Table 2). The new variable entering the model (principal component one) is highly significant; the SE (estimate) of 9 lambs is marginally better than the SE of 10 from the first model, and the adjusted R^2 is higher (Table 5). The model is as follows:

$$\text{Lamb:ewe ratio} = 51.89999 - 11.13093 \text{ (principal component one).} \quad (2)$$

Predictions of lamb:ewe ratios from models 1 and 2 are listed (Table 2).

Predicted (model 2) and actual ratios are close for the first 10 years, but diverge for the last 4 years (Fig. 2). Divergence of lamb:ewe ratios from those predicted by the model suggest that unusual weather patterns or other perturbations may have influenced lamb counts. Divergence of lamb:ewe ratios or weather from the 10-year average patterns on which the model was constructed could affect the model's predictability.

Based on the model's predictions, lamb survival should have been higher by an average of eight lambs than ratios observed from 1986 through 1989 (Table 2). Eight lambs falls within the SE (estimate) of the model, and all predictions fall within the 95% prediction interval (Fig. 3). Regression

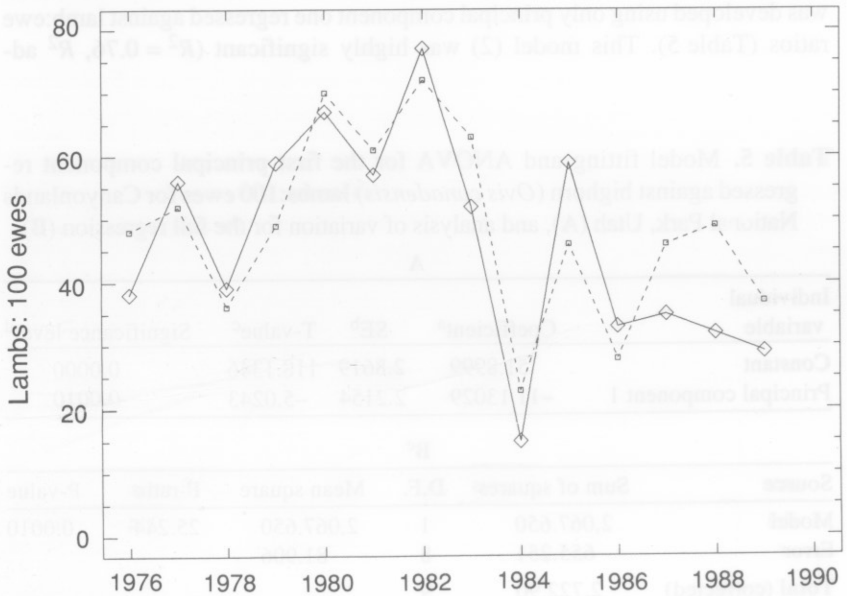

Fig. 2. Predicted desert bighorn lamb:ewe ratios (*small squares*) versus that measured on helicopter surveys (observed; *large squares*), Island-In-The-Sky herd, Canyonlands National Park, Utah.

residuals, when plotted, exhibited a random pattern and lay close to the line of a probability plot. No residuals were beyond 3 sigma. Predictions for 1987 and 1988 differed the most from observed ratios. The prediction of a higher or lower lamb:ewe ratio than that observed in the fall survey suggests one or more of the following:

- some variables are out of their normal range,
- sighting errors occurred during surveys,
- the model is flawed,
- density is becoming limiting, or
- removals have changed reproduction in the herd.

Each weather parameter in the model and lamb:ewe ratios were compared graphically, by year, to aid in evaluation of unusual weather events that could have affected the predictions. The lamb:ewe ratios were compared to precipitation from January through March 2 years earlier (Fig. 4). The graphs show strong similarities—the only notable divergence occurred in 1989 when precipitation increased while the lamb:ewe ratio decreased. Overall, the patterns seem insignificantly different and do not help explain 1986–89 predictions. Precipitation from January through March from 2 years earlier is

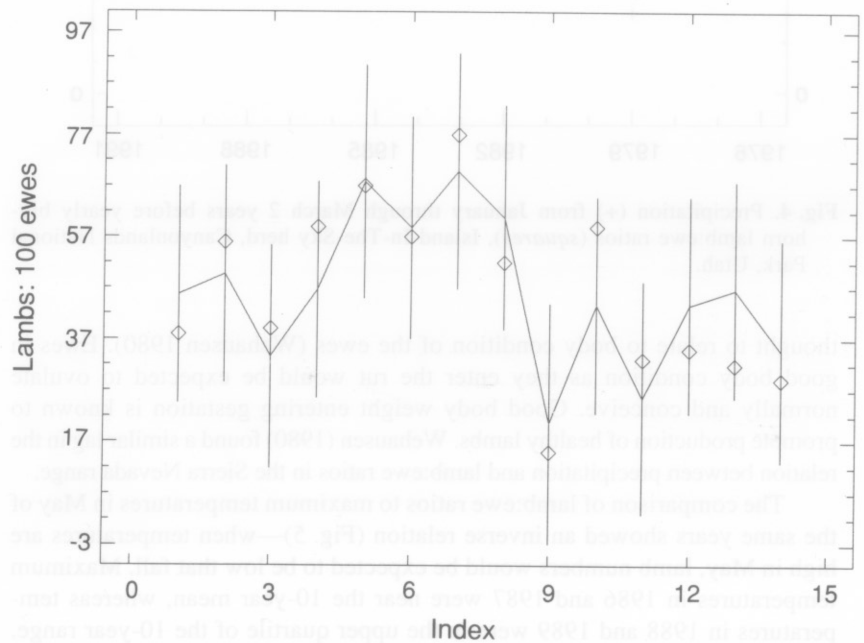

Fig. 3. Graph of predicted (*line*) versus observed (*squares*) lamb:ewe ratios with the 95% prediction interval, Island-In-The-Sky herd, Canyonlands National Park, Utah.

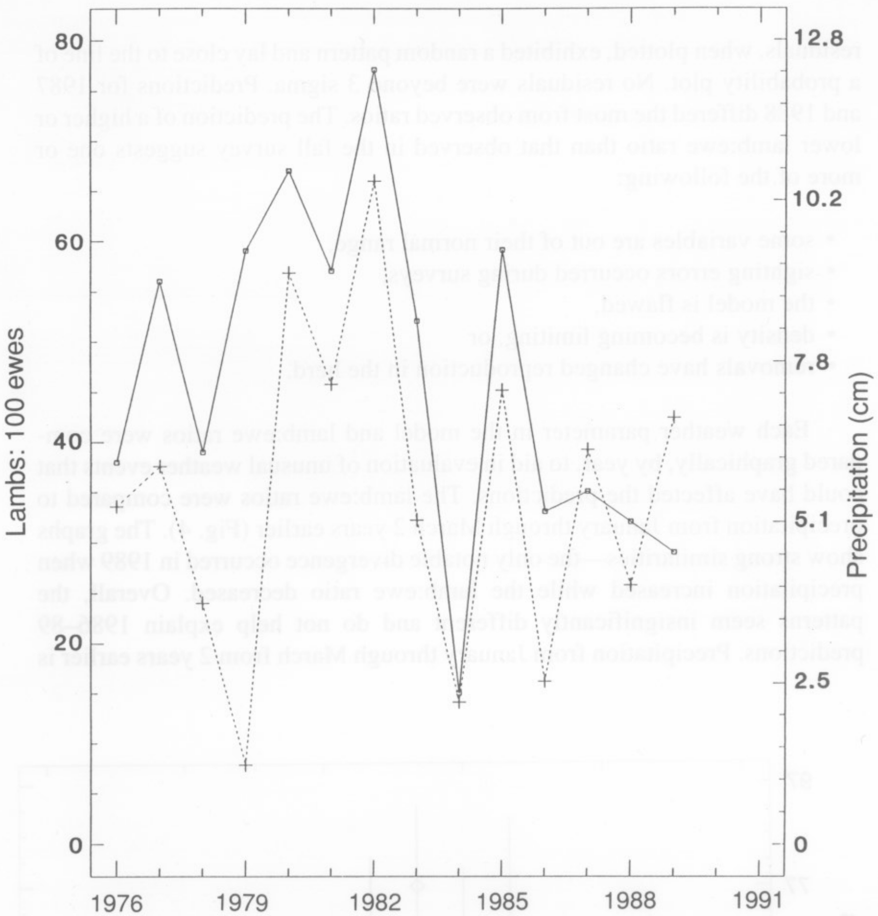

Fig. 4. Precipitation (+) from January through March 2 years before yearly bighorn lamb:ewe ratios (*squares*), Island-In-The-Sky herd, Canyonlands National Park, Utah.

thought to relate to body condition of the ewes (Wehausen 1980). Ewes in good body condition as they enter the rut would be expected to ovulate normally and conceive. Good body weight entering gestation is known to promote production of healthy lambs. Wehausen (1980) found a similar lag in the relation between precipitation and lamb:ewe ratios in the Sierra Nevada range.

The comparison of lamb:ewe ratios to maximum temperatures in May of the same years showed an inverse relation (Fig. 5)—when temperatures are high in May, lamb numbers would be expected to be low that fall. Maximum temperatures in 1986 and 1987 were near the 10-year mean, whereas temperatures in 1988 and 1989 were in the upper quartile of the 10-year range. Maximum temperatures in May of the same year were thought to be important because May is the first month in which moisture demand by the

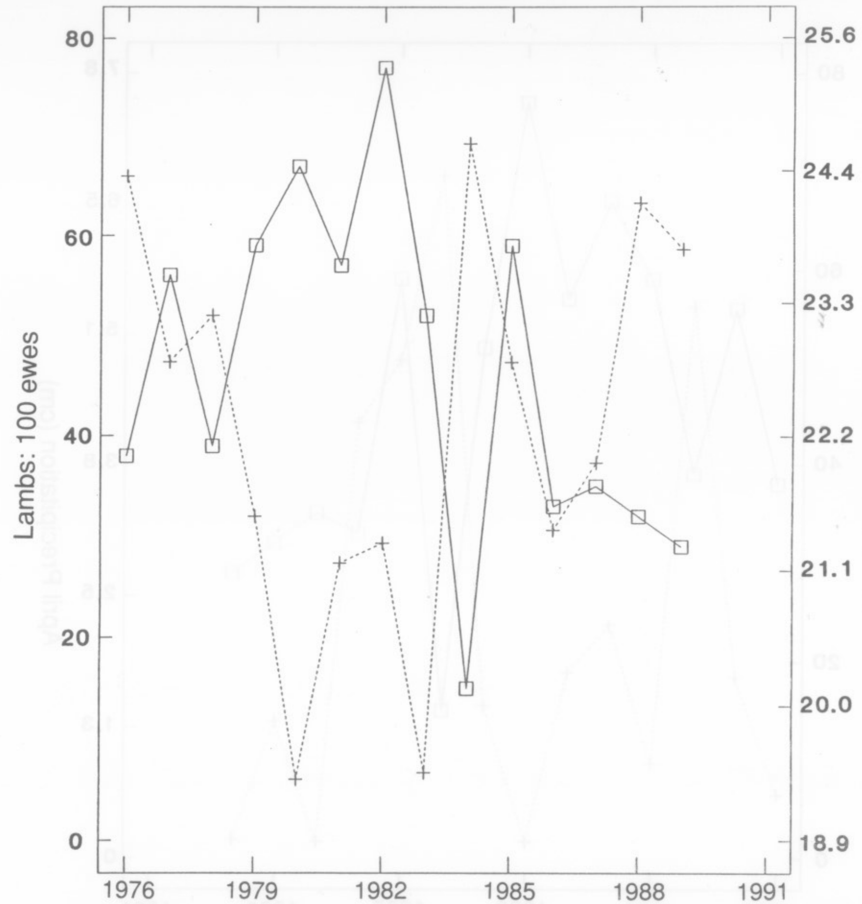

Fig. 5. Maximum May temperatures (+) as related to yearly lamb:ewe ratios (*squares*), Island-In-The-Sky herd, Canyonlands National Park, Utah.

vegetation may exceed soil moisture storage (Fig. 1). The soil moisture shortage results in drying of forage plants and a decrease in nutrient content (Hull 1984). Precipitation in early May could prolong higher forage nutrients by delaying the drying of forage. Although this rationale would seem to hold for April precipitation as well, the data show that April precipitation negatively influences lambs. Holl and Bleich (1983) found a similar inverse relation between lamb:ewe ratios and April precipitation for desert bighorn in the San Gabriel Mountains, California. In that area, however, May precipitation also was negatively related to lamb:ewe ratios.

Precipitation in April and the lamb:ewe ratio of the same year yields an inverse relation (Fig. 6). April is typically a dry month, averaging 2.59 cm of precipitation per year for 1976–90. Low minimum temperatures prevail throughout the month. Thus, above average precipitation in April has a high probability of occurring during cold, stormy weather and during the peak of

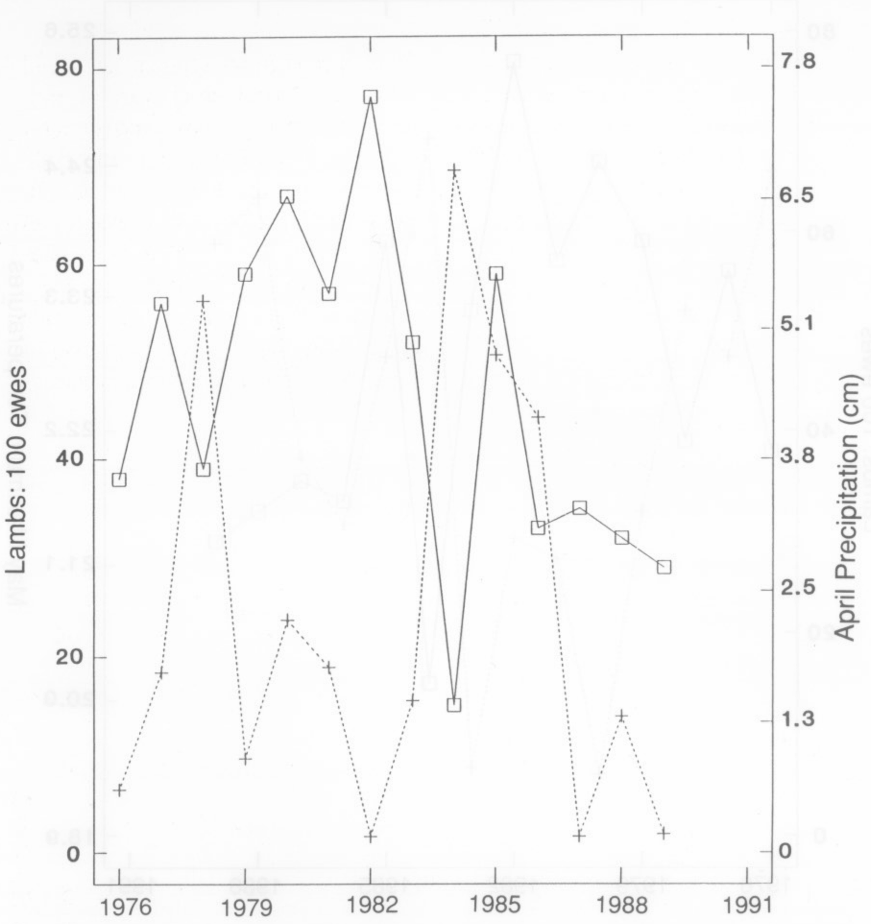

Fig. 6. April precipitation (+) as related to yearly lamb:ewe ratios (*squares*), Island-In-The-Sky herd, Canyonlands National Park, Utah.

lambing. Despite above average April precipitation in 1984–86, lamb numbers were less than expected in only 1984 and 1986. There is an interaction with temperatures in 1984 that is not readily apparent here. April 1984 had severely cold temperatures, and precipitation arrived as a hail and sleet storm. As a result, the fall 1984 lamb:ewe ratio of 15 lambs:100 ewes was the lowest on record. Minimum temperatures in April and other months, or combinations of months, did not enter the model because of low correlations with lamb:ewe ratios. Several indices incorporating minimum temperatures and precipitation were developed in an unsuccessful attempt to add minimum temperatures into the model. Below average (<2.59 cm) amounts of precipitation in Aprils of 1987–89 should have promoted above average numbers of lambs, if April precipitation alone was the major determinant.

The negative effects on lambs of May's maximum temperatures and April's precipitation are seen in 1984 when both parameters were at high extremes (Figs. 5 and 6). The relation of weather patterns and general depression of lamb numbers for 1986–89 is less clear. Precipitation in 1988 and 1989 was considerably below normal—1989 was the driest of the past 16 years. It is not clear from the weather records (Figs. 4–6) why the model predicted higher lamb:ewe ratios in 1987–88 than were observed. Nevertheless, the predictions were well within the 95% prediction interval (Fig. 3).

The numbers of lambs:100 ewes as related to numbers of animals removed during 1982–86 seemed to indicate instability following removal of lambs (Fig. 7). Removals in 1982 and 1983 were conducted during years of

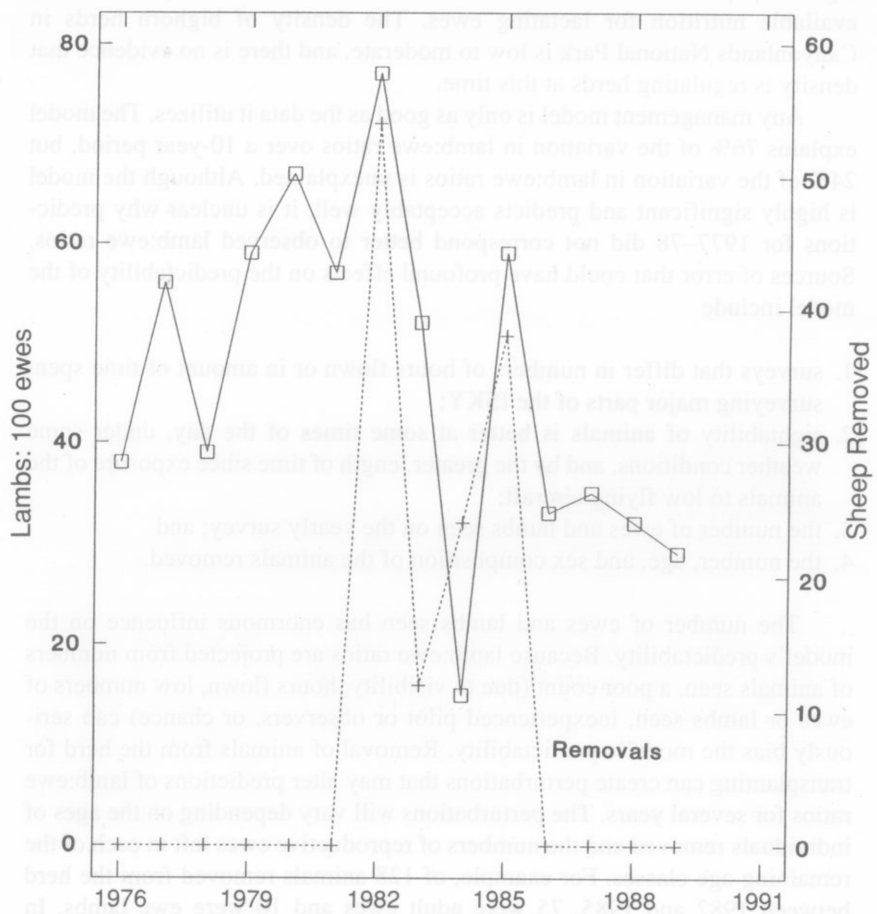

Fig. 7. Early lamb:ewe ratios (*squares*) and animal removals (+) from the Island-In-The-Sky bighorn herd, Canyonlands National Park, Utah.

good lamb survival and probable high herd density. Removals in 1984 were conducted during the year of lowest lamb survival on record. The removals in 1984 and 1985 might not have been attempted if removals had been based on the number of animals seen on surveys rather than on a population estimate.

Continuation of yearly monitoring of the ISKY herd is important for a number of reasons. The 14-year data base for this herd is almost unique for desert bighorn herds managed by the National Park Service. Only the River Mountain herd at Lake Mead has a longer record of surveys.

Lamb recruitment is the major cause of fluctuations in herd size of desert bighorn—predation and mortality of adults generally exert a minor influence on population size; but they can have a significant effect on small, transplanted groups. High density (i.e., at or above carrying capacity) in bighorn populations can lead to lower survival of lambs by decreasing available nutrition for lactating ewes. The density of bighorn herds in Canyonlands National Park is low to moderate, and there is no evidence that density is regulating herds at this time.

Any management model is only as good as the data it utilizes. The model explains 76% of the variation in lamb:ewe ratios over a 10-year period, but 24% of the variation in lamb:ewe ratios is unexplained. Although the model is highly significant and predicts acceptably well, it is unclear why predictions for 1977–78 did not correspond better to observed lamb:ewe ratios. Sources of error that could have profound effects on the predictability of the model include

1. surveys that differ in numbers of hours flown or in amount of time spent surveying major parts of the ISKY;
2. sightability of animals is better at some times of the day, under some weather conditions, and by the greater length of time since exposure of the animals to low flying aircraft;
3. the number of ewes and lambs seen on the yearly survey; and
4. the number, age, and sex composition of the animals removed.

The number of ewes and lambs seen has enormous influence on the model's predictability. Because lamb:ewe ratios are projected from numbers of animals seen, a poor count (due to visibility, hours flown, low numbers of ewes or lambs seen, inexperienced pilot or observers, or chance) can seriously bias the model's predictability. Removal of animals from the herd for transplanting can create perturbations that may alter predictions of lamb:ewe ratios for several years. The perturbations will vary depending on the ages of individuals removed and the numbers of reproductive ewes left in each of the remaining age classes. For example, of 128 animals removed from the herd between 1982 and 1985, 75 were adult ewes and 10 were ewe lambs. In 1982–85, 36, 8, 17, and 24 ewes and ewe lambs were removed. Ewes of

reproductive age usually were selected to enhance reproductive potential at the new site. Removal of 30 adult ewes in 1985 from a herd of 300 animals would have represented one-fifth of the herd's reproductive potential. Removals of animals 4 years in a row could easily have altered age structures in the herd and added to the variance seen in the model's predictions.

The park should strive for consistency in its surveys each year by using the same number of flight hours and equipment, following the same pattern of coverage, using the same personnel where possible, conducting the surveys at the same time, and using comparable sight conditions. Major segments of bighorn habitat should be clearly delineated on maps and the data recorded by segments. In future years, analysis of the data by segments might provide guidance concerning ways to reduce the magnitude of the sampling by counting representative sections to track population trends instead of the entire area.

Park bighorns presently use adjacent lands administered by the Bureau of Land Management, and transplanted populations occur between the park and Indian Nation lands to the south. It is critical that park sheep be managed on a regional basis in concert with other agencies. National Park Service (NPS) lands in southern Utah are insufficient in themselves to ensure long-term survival of bighorns in the area. I recommend continued use of the ISKY herd as a source of animals for reintroducing additional herds in and around Canyonlands National Park. Application of the predictive model and continued survey data will help managers decide when herd density is sufficient to sustain removal of animals.

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Literature Cited

Bartmann, R. M., and D. C. Bowen. 1984. Predicting mule deer mortality from weather data in Colorado. Wildlife Society Bulletin 12:246–248.

Caughley, G., G. C. Grigg, and L. Smith. 1985. The effect of drought on kangaroo populations. Journal Wildlife Management 49:679–685.

Caughley, G., N. Shepherd, and J. Short, editors. 1987. Kangaroos: their ecology and management in the sheep rangelands of Australia. Cambridge Studies in Applied Ecology and Resource Management, Cambridge University Press, New York. 253 pp.

Douglas, C. L. 1991. Predicting lamb survival from weather patterns in Canyonlands National Park, Utah. National Park Service, CPSU/UNLV 031/08, University of Nevada, Las Vegas. 24 pp.

Douglas, C. L., and C. R. Annable. 1985. A model of climatic variables affecting bighorn lamb survival in Canyonlands National Park. National Park Service, CPSU/UNLV 031/02, University of Nevada, Las Vegas. 18 pp.

Douglas, C. L., and D. M. Leslie, Jr. 1986. Influence of weather and density on survival of desert mountain sheep. Journal of Wildlife Management 50:153–156.

Holl, S. A., and V. C. Bleich. 1983. San Gabriel mountain sheep: biological and management considerations. Administrative report, San Bernardino National Forest, San Bernardino, Calif. 136 pp.

Hull, W. B. 1984. Seasonal nutrition of desert bighorn sheep in Canyonlands National Park, Utah. M.S. thesis, Utah State University, Logan. 88 pp.

Laurance, W. F., and E. Yensen. 1985. Rainfall and winter sparrow densities: a view from the northern Great Basin. Auk 102:152–158.

Leopold, A. 1933. Game management. Charles Scribner's Sons, New York. 481 pp.

Loope, W. L. 1977. Relationships of vegetation to environment in Canyonlands National Park. Ph.D. dissertation, Utah State University, Logan. 142 pp.

Manly, B. F. J. 1986. Multivariate statistical methods: A prime. Chapman and Hall Ltd., London. 159 pp.

Mather, J. R. 1979. Use of the climatic water budget in selected environmental water problems. Publications in Climatology, Vol. 32(1), C. W. Thornthwaite Associates, Laboratory of Climatology, Elmer, N.J. 39 pp.

McClave, J. T., and F. H. Dietrich II. 1988. Statistics. Dellen Publishing Company, San Francisco. 1,014 pp.

Owen-Smith, N. 1990. Demography of a large herbivore, the greater kudu *Tragelaphus strepsiceros*, in relation to rainfall. Journal of Animal Ecology 59:893–913.

Picton, H. D. 1979. A climate index and mule deer fawn survival in Montana. International Journal of Biometeorology 23:115–122.

Picton, H. D. 1984. Climate and the prediction of reproduction of three ungulate species. Journal of Applied Ecology 21:869–879.

Verme, J. L. 1968. An index of winter weather severity for northern deer. Journal of Wildlife Management 32:566–574.

Wehausen, J. D. 1980. Sierra Nevada bighorn sheep: history and population ecology. Ph.D. dissertation. University of Michigan, East Lansing. 240 pp.

Wehausen, J. D., V. C. Bleich, B. Blong, and T. L.Russi. 1987. Recruitment dynamics in a southern California mountain sheep population. Journal of Wildlife Management 51:86–98.